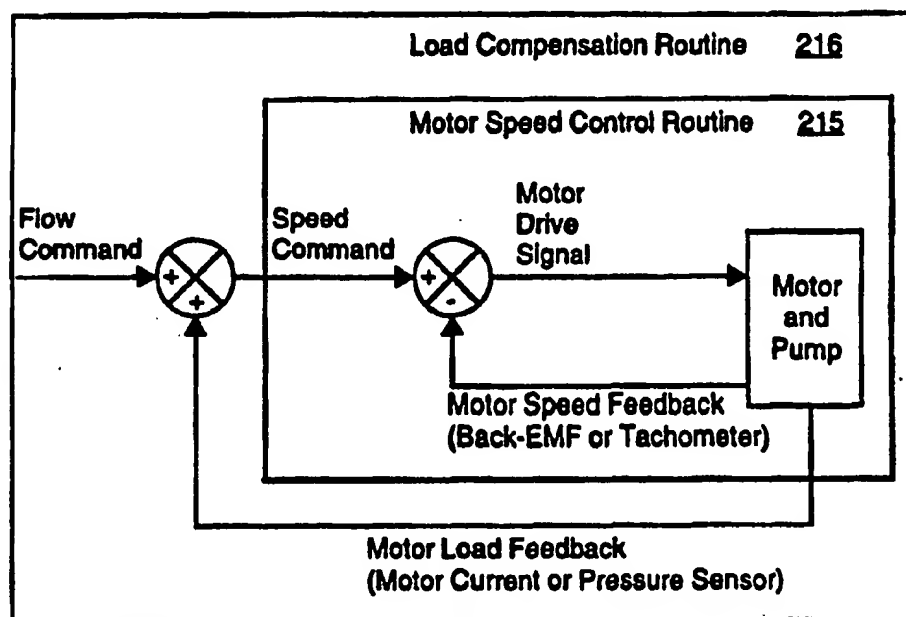




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

| | | |
|---|---|---|
| (51) International Patent Classification ⁶: F04B 49/06 | A1 | (11) International Publication Number: WO 95/09305 (43) International Publication Date: 6 April 1995 (06.04.95) |
| (21) International Application Number: PCT/CA94/00517 (22) International Filing Date: 20 September 1994 (20.09.94) (30) Priority Data: 127,162 27 September 1993 (27.09.93) US (71) Applicant: DIVERSEY CORPORATION [CA/CA]; Suite 1600, 1 Robert Speck Parkway, Mississauga, Ontario L4Z 3S9 (CA). (72) Inventors: LIVINGSTON, James, W.; 27 South Circle Drive, Santa Cruz, CA 95060 (US). HOSKING, Stephen; 320 Swift Street, Santa Cruz, CA 95060 (US). (74) Agent: WOODLEY, John, H.; Sim & McBurney, Suite 701, 330 University Avenue, Toronto, Ontario M5G 1R7 (CA). | (81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ). Published <i>With international search report.</i> <h1 style="text-align: center;">BEST AVAILABLE COPY</h1> | |

(54) Title: FLOW-METERED PUMPING WITH LOAD COMPENSATION SYSTEM AND METHOD

**(57) Abstract**

The present invention is an improved flow-metered pumping system using an air-backed diaphragm pump with load compensation. A variable motor speed controller is used to compensate for flow rate reduction caused by pressure effects. When the output pressure on the pump increases to a point where the load on the pump motor exceeds a specified threshold, the motor speed controller increases the speed of the motor to compensate for pressure induced diaphragm distortion losses and to achieve a substantially constant flow rate across a range of pump output pressures.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

| | | | | | |
|----|--------------------------|----|---------------------------------------|----|--------------------------|
| AT | Austria | GB | United Kingdom | MR | Mauritania |
| AU | Australia | GE | Georgia | MW | Malawi |
| BB | Barbados | GN | Guinea | NE | Niger |
| BE | Belgium | GR | Greece | NL | Netherlands |
| BF | Burkina Faso | HU | Hungary | NO | Norway |
| BG | Bulgaria | IE | Ireland | NZ | New Zealand |
| BJ | Benin | IT | Italy | PL | Poland |
| BR | Brazil | JP | Japan | PT | Portugal |
| BY | Belarus | KE | Kenya | RO | Romania |
| CA | Canada | KG | Kyrgyzstan | RU | Russian Federation |
| CF | Central African Republic | KP | Democratic People's Republic of Korea | SD | Sudan |
| CG | Congo | KR | Republic of Korea | SE | Sweden |
| CH | Switzerland | KZ | Kazakhstan | SI | Slovenia |
| CI | Côte d'Ivoire | LI | Liechtenstein | SK | Slovakia |
| CM | Cameroon | LK | Sri Lanka | SN | Senegal |
| CN | China | LU | Luxembourg | TD | Chad |
| CS | Czechoslovakia | LV | Latvia | TG | Togo |
| CZ | Czech Republic | MC | Monaco | TJ | Tajikistan |
| DE | Germany | MD | Republic of Moldova | TT | Trinidad and Tobago |
| DK | Denmark | MG | Madagascar | UA | Ukraine |
| ES | Spain | ML | Mali | US | United States of America |
| FI | Finland | MN | Mongolia | UZ | Uzbekistan |
| FR | France | | | VN | Viet Nam |
| GA | Gabon | | | | |

- 1 -

**FLOW-METERED PUMPING WITH LOAD COMPENSATION
SYSTEM AND METHOD**

FIELD OF THE INVENTION

The present invention relates generally to metered
5 pumping systems, and particularly to a constant flow
pumping system using air-backed diaphragm pumps.

BACKGROUND OF THE INVENTION

Air-backed diaphragm pumps provide an economical and
reliable solution for many fluid handling applications.
10 However, they are not suitable for use in a system where a
precise or highly stable flow rate is required. The flow
rate of such pumps drops with increasing pressure on the
pump outlet for several reasons. First, the increased load
slows the motor down resulting in a reduced flow rate.
15 Second, the unsupported regions of the pump diaphragm
balloon slightly in proportion to the pressure on the
outlet, reducing the effective displacement and flow rate
of the pump. These diaphragm distortion-based flow rate
losses are independent of motor type.

20 While load induced motor speed reductions can be
compensated by using control techniques well known in the
art, such correction techniques only counteract about 70%
of pressure induced flow rate losses. These techniques do
not compensate for diaphragm distortion-based flow rate
25 losses which can account for up to 30% of the pressure
induced flow reduction.

One method of eliminating the distortion based
diaphragm flow rate loss is to support the diaphragm with
some incompressible liquid in a sealed chamber behind the
30 diaphragm. However, such liquid-backed pumps are
inefficient and relatively expensive compared to air-backed
pumps. Alternatively, a rotor vane pump can be used
instead of a diaphragm pump. A rotor vane pump can
accurately maintain a specified flow rate through varied
35 outlet pressures. However, rotor vane pumps are very
expensive. Moreover, rotor vane pumps cannot pump fluids
containing large particulates (> 50 micron) and as a result
require the use of micro filters to screen any fluid that

- 2 -

is pumped. Air-backed diaphragm pumps, on the other hand, are inexpensive and can pump fluids with relatively large particulates without impairing the pump.

An object of the invention is to provide a low cost
5 metered flow pumping system that provides substantially constant flow rate across a range of pump output pressures.

Another object of the present invention is to provide a metered flow pumping system that is not sensitive to the presence fluid particulates.

10 Another object of the invention is to provide a metered flow pumping system using an air-backed diaphragm pump.

SUMMARY OF THE INVENTION

In summary, the present invention is an improved
15 flow-metered pumping system using an air-backed diaphragm pump with load compensation. A variable motor speed controller is used to compensate for flow rate reduction caused by pressure effects. The load on the motor driving a diaphragm pump increases in proportion to the pressure on
20 the output of the pump. This load is measured and used in a feedback loop to increase the speed of the motor. The gain of this feedback loop is set at such a level as to compensate for pressure induced diaphragm distortion losses and to achieve substantially constant flow rate across a
25 range of pump output pressures.

In accordance with an aspect of the invention, a flow-metered pumping system, comprises:

a pump for pumping a liquid;

a pump motor for driving the pump, the pump motor
30 including a motor driver for supplying power to the pump motor;

a speed sensor, coupled to the pump motor, for generating a speed signal corresponding to the pump motor's speed;

35 a load sensor, coupled to the pump motor, for generating a load signal corresponding to the pump motor's load;

- 3 -

speed control means, coupled to the motor driver and to the speed sensor, for maintaining the speed of the pump motor at a specified speed; the speed control means including a negative feedback means for modulating the amount of power supplied by the motor driver to the pump motor according to the speed signal and the specified speed;

speed compensation means, coupled to the speed control means and to the load sensor, for maintaining a substantially constant flow rate through the pump; the speed compensation means including a positive feedback means for adjusting the specified speed according to the load signal and a specified base speed.

According to a further aspect of the invention, a flow-metered pumping system comprises:

- a motor driven pump for pumping a liquid;
- a load sensor coupled to the pump for generating a load signal corresponding to loading on the pump;
- a speed sensor coupled to the pump for generating a speed signal corresponding to the pump's speed;
- speed control means, coupled to the pump, the load sensor, and the speed sensor for maintaining a substantially constant flow of the liquid through the pump corresponding to a specified base pump speed; the speed control means including feedback means for modulating said pump's speed according to the load signal, the speed signal, and the specified base speed such that the pump's speed is increased by the speed control means as the load signal increases in value.

In accordance with a further aspect of the invention, a method of flow-metered pumping comprises:

- providing a pump for pumping a liquid;
- operating a pump motor for driving the pump; the pump motor including a motor driver for supplying power to the pump motor;
- measuring the pump motor's load;
- measuring the pump motor's speed;

- 4 -

maintaining a substantially constant flow rate through the pump, including modulating the pump motor's speed according to measured load, the measured speed and a specified base flow rate such that the pump motor's speed is increased as the measured load increases.

BRIEF DESCRIPTION OF THE DRAWINGS

Additional objects and features of the invention will be more readily apparent from the following detailed description and appended claims when taken in conjunction with the drawings, in which:

Figure 1 is a block diagram of a washing machine system that uses the flow-metered pumping system of the instant invention to provide a constant flow rate of chemical solution to the washing machines.

Figure 2 is a block diagram of the flow-metered pumping system of the instant invention.

Figure 3 depicts a pump motor drive circuit and the drive and measurement signals associated therewith.

Figure 4 depicts a graph showing the motor speed for an air-backed diaphragm pump needed to maintain a constant flow rate for a range of motor loads.

Figure 5 is a flow chart for a dual control loop to maintain a constant flow through an air-backed diaphragm pump.

Figure 6 is a timing diagram showing the sequence of flow control steps used in the dual control loop embodiment of the present invention.

Figure 7 is a flow chart for an alternate control method to maintain a constant flow through a pump.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows a washing machine system 100 utilizing metered flow pump controllers 102-1, 102-2, 102-3 of the present invention. The washing machine system includes washing machines 104-1 to 104-6 which receive chemical solution pumped at a measured flow rate by pumps 111-116. These metered-flow pumps are controlled by metered flow pump controllers 102-1 to 102-3. Each pump controller 102

- 5 -

can control up to two pumps. Each of the two pumps attached to one controller can feed a separate washer or they both can be attached to a single washer to provide double the maximum flow of solution to that washer. Washer 104-1 is shown connected to a single pump 111, which is one of two pumps controlled by metered flow controller 102-1. Pump 111 draws chemical solution from main conduit 30 and delivers the solution to washer 104-1 via feed conduit 31. Other washers in the system are connected to the pumps and main conduit in a similar manner.

Master controller 120 coordinates the various subsystems of the washing machine system. It communicates to the pump controllers and washing machines over serial connection line 121. In the instant embodiment, this serial connection is implemented using a RS 485 communication protocol. The master controller 120 specifies desired flow rates to the metered-flow pump controllers 102 over serial connection line 121.

Figure 2 shows the metered flow pumping system of the instant invention including the controller 102, and two pumps 111, and 112. The instant invention has the capability to independently regulate two pumps but can be operated to control a single pump or multiple pumps without departing from the scope of the invention. Each pump 111, 112 consists of a pulse controlled permanent magnet DC motor 130, motor driver 132, and an air-backed diaphragm pump 134. The motor drivers 132 deliver power to motors 130 according to the signals on pulse length modulation (PLM) signal lines 136 which are output from the controller 120.

The controller 102 consists of a CPU 210 which executes software 301 stored in a ROM 211 in conjunction with a RAM 212 for manipulating controller hardware to perform control functions. The ROM 211 stores control programs 214-216 and data tables 218-221. The data tables hold parameters used by the controller software in controlling the pump motors. The controller also has a timer 213 for scheduling the execution of control

- 6 -

functions. A-D converters 230, 231 translate analog signals from the pump motors into digital values that are used by the CPU 210. The controller has output port registers 232 and 233 connected to PLM signal lines 234, 235. The CPU 210 writes to these registers to control the PLM signal lines 234, 235. Finally, the controller has I/O interface 240 sending and receiving messages to and from an outside source using the RS 485 communication protocol. In the preferred embodiment, all of the controller elements are contained within a 68HC705B5 single chip micro-controller, but they can be built using discrete components without departing from the scope of the invention. Other micro-controllers, preferably with built-in analog to digital converters, could be used in alternate embodiments.

The controller software 214-216 instructs the CPU 210 to calculate the amount of time that the PLM signals output on lines 234, 235 should be ON in a given cycle according to the control algorithms discussed below. The CPU 210 programs the timer 213 to generate a signal at the specified time interval. The CPU 210 writes a high value to the output port corresponding to a PLM signal to turn on that PLM signal and writes a low value to the same output port to turn off the PLM signal when the timer 213 indicates that the specified time has elapsed.

The PLM signals are periodic (8.192 ms cycle time in the instant embodiment) and control power to the pump motor. When a PLM signal is high the motor is supplied with power that causes acceleration. When the PLM signal is low the power is cut off and the motor coasts. The speed of a motor can be controlled by adjusting the duty cycle of the PLM signal. The more that the signal is "on" during a cycle, the faster the motor will rotate.

Referring to Figures 2 and 3, each motor provides the controller with two sense signals. The motor back-emf signals received on lines 241, 242 are used by the controller as a measure of motor speed. Motor speed can be measured by other means such as an encoder or tachometer

- 7 -

without departing from the scope of the invention. The motor current signals received on lines 243 and 244 are used by the controller as an indication of the load on each motor. Motor loading can also be measured by other means
5 such as a torque or pressure sensor without departing from the scope of the invention.

The measurement of the back-emf signal is synchronized with the PLM drive signal. The controller software reads the back-emf signal at the end of the PLM drive cycle just
10 before the PLM signal is turned on for the next drive cycle. This timing allows the measurement of a motor's back-emf without interference from the PLM drive signal. The timing of the motor current signal is not critical. In the instant embodiment, the motor current is read in the
15 middle of the PLM cycle but can be read at other points in the PLM drive cycle without effecting the operation of the invention.

Figure 4 depicts a motor speed and motor load graph that shows relationship between motor speed and motor load
20 for an air-backed diaphragm pump for two different flow rates. As shown, in order to maintain a constant flow rate through the pump, as the load (i.e., output pressure) on the pump increases past a threshold load, the motor speed must be increased in order to maintain a constant flow
25 rate. Also shown in Figure 4 is that the threshold load is different for different flow rates and that different positive feedback gains are needed to maintain different flow rates.

Figure 5 shows the feedback control system implemented
30 by the controller 210. The controller uses a dual feedback loop system to control the flow rate through the motor. The controller 210 executes a first motor speed feedback routine 215 to control motor speed. The controller uses a specified Speed Command value as the target motor speed.
35 It gets a back-EMF signal from the motor that is proportional to motor speed. The timer is used to signal the controller when to read the back-EMF signal. The A-D converters are used to convert the analog back-emf signal

- 8 -

into a digital signal for manipulation by the CPU. The controller uses the digital conversion of the back-EMF signal and speed command value to select the duty cycle for the PLM signal. An error value proportional to the difference between the actual speed (as reflected by the digitized back-EMF signal) and the speed command value is generated by the controller. The change in the PLM signal duty cycle is determined by multiplying the error by a proportional gain signal and adding the integral of the error with respect to time multiplied by an integral gain value. This change value is added to a "steady state" PLM duty cycle value that is determined by multiplying the speed command value by an initial gain. The following pseudocode shows the operation of the controller software implementing the first feedback loop:

```
Speed Control
{
  Receive Back_emf
  error = SpeedCommand - Back_emf
  accum = accum + (error * IntegralGain)
  clip accum to predefined range
  temp = (SpeedCommand * InitialGain) +
         (error * ProportionalGain) + accum
  clip temp to predefined range
  PLM duty cycle = temp
  -- controller will continue to drive motor with
  this computed
  -- PLM duty cycle until this value is updated
}
```

This routine is executed once during each PLM drive cycle after the back-emf has been read.

The control software includes a second feedback loop routine 216 to adjust the speed command value used by the first feedback loop to compensate for diaphragm distortion-induced flow rate losses at high output pressures. The controller receives an externally sourced flow command value over the RS 485 link that specifies the target flow rate through the pump. The flow command value in the preferred embodiment is actually a base pump speed value which will achieve a desired flow rate if the load on the pump motor is very low.

- 9 -

The controller gets a motor current signal from the motor that is proportional to the load on the motor. The controller uses the motor current and flow command value to select an appropriate speed command value. The motor
5 current is compared to a threshold value. If the motor current is greater than the threshold, the difference between the motor current and the threshold is multiplied by a flow gain and added to the flow command value to generate a new speed command value for the motor speed
10 feedback routine 215. As the load increases, the speed command value is increased to compensate for throughput losses caused by pressure effects. The following pseudocode shows the operation of the controller software implementing the second control loop:

15

```
Load Compensation
```

```
{  
  Receive MotorCurrent  
  if MotorCurrent > Threshold then  
20    {  
      SpeedCommand = FlowCommand +  
        ( (MotorCurrent - Threshold) * FlowGain )  
    }  
  else SpeedCommand = FlowCommand  
25  Return  
}
```

The positive feedback gain coefficient, FlowGain, in this routine is computed from flow and speed measurements
30 of actual air-backed diaphragm pumps so that the flow rate of fluid through the pump remains substantially constant for a specified range of output pressures or motor loads. This routine is executed once during each PLM cycle just after the motor current signal has been read.

35 Each time a new flow command value is received over the RS 485 port the CPU 210 executes an initialization routine 213. The initialization routine selects values for the flow gain, proportional gain and integral gain, and motor current threshold using the data tables 218-221.
40 There is a separate table for each of these parameters. Each table consists of a sequence of flow rate / value

- 10 -

pairs. The value paired with a flow rate is the optimized parameter value corresponding to that flow rate. These pairs are stored in the table in sequence of increasing flow rates. The initialization routine scans the table starting at the highest flow rate and locates the largest flow rate that is less than or equal to the new flow command. The parameter is initialized to the value corresponding this located flow rate. Using a parameter lookup table indexed according to flow rate allows the controller software to be optimized for broad range of flow rates. In the preferred embodiment, the parameters can also be down-loaded over the serial link, allowing the master controller to optimize the control software for certain situations.

The initialization routine then ramps the motor speed up or down to the desired flow rate by increasing or decreasing speed command value by a constant amount each cycle until the target motor speed is reached. Once up to speed, the initialization routine then enables the dual loop control algorithm to control speed and compensate for load. The following pseudocode shows the flow of the initialization routine:

```

Initialize
25      {
        Receive FlowCommand
        if FlowCommand is New
        {
30          Threshold = ThresholdTable(FlowCommand)
          FlowGain = GainTable(FlowCommand)
          InitialGain = InitGainTable(FlowCommand)
          ProportionalGain = PropGainTable(FlowCommand)
          Ramp SpeedCommand up or down
          until SpeedCommand = FlowCommand
35      }
        Return
    }

    ThresholdTable(FlowCommand)
40      -- Note structure of Threshold table is
      -- Table(Flow(1:N),Threshold(1:N))
      Index = 1
      Do For Index = 1 to N
45          {
            If Flow(Index) ≤ FlowCommand {

```

- 11 -

```
                                Return (Threshold(Index)) }  
                                }  
    Return (Threshold(N))  
  
5      -- The FlowGain, InitialGain and ProportionalGain  
      functions all  
      -- work in the same way as the ThresholdTable  
      function, except  
10     -- that the flow value breakpoints may be  
      different in each table.
```

Figure 6 is a timing diagram showing the timing relationship between the measurement of motor signals, the motor drive signals, and the software implementing the dual loop control algorithm. When the PLM motor drive signal is high in Figure 6, the motor is receiving power that causes acceleration. When the motor drive signal is low the motor receives no power and coasts. The back-EMF waveform represents the back-emf of the motor driven by the PLM motor drive signal. The current sense waveform shows the current through the motor driven by the PLM motor drive signal.

Motor current and back-emf measurement timing is linked to the motor drive timing because the back-emf must be sensed at the end of the drive interval just before the "on" portion of the drive waveform begins. The current measurements are made near the middle of the PLM drive cycle. The PLM motor drive signal is turned on and off according to the output of the controller timer. That same timer is used to signal the controller software to measure current and back-emf, thereby insuring that there is a precise relationship between the PLM drive signal and the motor signal measurement points.

The motor current is read shortly after the motor drive signal is turned off. The load compensation routine 216 then executes and calculates a speed command value for use by the first control loop routine. The timer is programmed to cause a back-emf read a specified time before the start of the next PLM drive cycle. The speed control routine 215 is executed after the back-emf has been measured to calculate a new duty cycle value for the PLM

- 12 -

drive signal that will be used by a counter to control the "on" portion of the subsequent PLM duty cycle.

Figure 7 shows the flow of an alternative method of controlling the motor using only a single control loop.

5 The controller implements a signal feed back loop to control motor speed. The controller uses a specified speed command value that is the target motor speed. It gets a signal from the motor, motor current that is proportional to the load on the motor. The controller uses the motor
10 current and speed command value to select the duty cycle for the PLM motor drive signal, increasing the duty cycle of the PLM motor drive signal as the load increases.

Controller software implementing a single control loop method has only a single feedback loop that performs both
15 the speed control and load compensation functions. The sequence of instructions in the software routine is similar to the first feedback loop control routine discussed above. In this embodiment, however, the specified flow command value is used instead of a speed command value as the
20 target motor speed. In addition load compensation is implemented by directly adjusting the PLM duty cycle rather than adjusting the target motor speed. The following pseudocode shows the operation of the controller software implementing this feedback loop:

25

Speed Control with Load Compensation

```

{
  Receive MotorCurrent
  Receive Back_emf
30  error = FlowCommand - Back_emf
  accum = accum + (error * IntegralGain)
  clip accum to predefined range
  temp = (FlowCommand * InitialGain) +
        (error * ProportionalGain) + accum
35  if MotorCurrent > Threshold then
    temp = temp + ((MotorCurrent - Threshold) *
                  FlowGain)
  clip temp to predefined range
  PLM duty cycle = temp
40  }

```

This routine is executed once during each PLM cycle after motor current and back-emf have been measured.

- 13 -

Although preferred embodiments of the invention are described herein in detail, it will be understood by those skilled in the art that variations may be made thereto without departing from the spirit of the invention or the

5 scope of the appended claims.

CLAIMS

1. A flow-metered pumping system, comprising:
a pump for pumping a liquid;
a pump motor for driving said pump, said pump motor
5 including a motor driver for supplying power to said pump motor;
a speed sensor, coupled to said pump motor, for generating a speed signal corresponding to said pump motor's speed;
10 a load sensor, coupled to said pump motor, for generating a load signal corresponding to said pump motor's load;
speed control means, coupled to said motor driver and to said speed sensor, for maintaining the speed of said
15 pump motor at a specified speed; said speed control means including a negative feedback means for modulating the amount of power supplied by said motor driver to said pump motor according to said speed signal and said specified speed;
20 speed compensation means, coupled to said speed control means and to said load sensor, for maintaining a substantially constant flow rate through said pump; said speed compensation means including a positive feedback means for adjusting said specified speed according to said
25 load signal and a specified base speed.

2. The flow-metered pumping system of claim 1, wherein said speed compensation means adjusts said specified speed in accordance with the following equation:

30

$$\text{Specified Speed} = \text{Base Speed} + (\text{PumpLoad} - \text{Threshold}) \\ * \text{Gain}$$

- when said load on said pump exceeds said Threshold, where
35 PumpLoad is a pump load value corresponding to said load signal, Threshold is a predefined pump load threshold value and Gain is a predefined positive feedback gain value.

- 15 -

3. A flow-metered pumping system comprising:
a motor driven pump for pumping a liquid;
a load sensor coupled to said pump for generating a
load signal corresponding to loading on said pump;
5 a speed sensor coupled to said pump for generating a
speed signal corresponding to said pump's speed;
speed control means, coupled to said pump, said load
sensor, and said speed sensor for maintaining a
substantially constant flow of said liquid through said
10 pump corresponding to a specified base pump speed; said
speed control means including feedback means for modulating
said pump's speed according to said load signal, said speed
signal, and said specified base speed such that said pump's
speed is increased by said speed control means as said load
15 signal increases in value.

4. The flow-metered pumping system of claim 1 or 3,
wherein:
said pump consists of an air-backed diaphragm pump.

20

5. The flow-metered pumping system of claim 3, wherein
said feedback means modulates said pump's speed in
accordance with the following equation:

25
$$\text{Pump Speed} = \text{Base Speed} + (\text{PumpLoad} - \text{Threshold}) * \text{Gain}$$

when said load on said pump exceeds said Threshold, where
PumpLoad is a pump load value corresponding to said load
30 signal, Threshold is a predefined pump load threshold value
and Gain is a predefined positive feedback gain value.

6. The flow-metered pumping system according to any one
of the preceding claims, wherein:
35 said pump motor consists of a pulsed activation,
permanent magnet DC motor;
said speed signal corresponds to said pump motor's
back-emf.

- 16 -

7. The flow-metered pumping system according to any one of the preceding claims, 7, wherein:

said pump motor consists of a pulsed activation, permanent magnet DC motor;

5 said load signal corresponds to said pump motor's current.

8. The flow-metered pumping system according to any one of the preceding claims, wherein:

10 said pump motor consists of a pulsed activation, permanent magnet DC motor;

said load signal corresponds to said pump motor's current;

15 said speed signal corresponds to said pump motor's back-emf.

9. A method of flow-metered pumping consisting of:

providing a pump for pumping a liquid;

20 operating a pump motor for driving said pump, said pump motor including a motor driver for supplying power to said pump motor;

measuring said pump motor's speed;

25 maintaining the speed of said pump motor at a specified speed, including modulating the amount of power supplied by said motor driver to said pump motor according to said speed signal and said specified speed;

measuring said pump motor's load; and

30 maintaining a substantially constant flow rate through said pump, including adjusting said specified speed according to said measured load and a specified base speed.

10. A method of flow-metered pumping consisting of:

providing a pump for pumping a liquid;

35 operating a pump motor for driving said pump; said pump motor including a motor driver for supplying power to said pump motor;

measuring said pump motor's load;

measuring said pump motor's speed;

- 17 -

maintaining a substantially constant flow rate through said pump, including modulating said pump motor's speed according to measured load, said measured speed and a specified base flow rate such that said pump motor's speed is increased as said measured load increases.

11. The method of claim 9 or 10, wherein:

said pump consisting of an air-backed diaphragm pump.

12. The method of claim 11, wherein said step of maintaining a substantially constant flow rate includes adjusting said specified speed in accordance with the following equation:

$$\text{Specified Speed} = \text{Base Speed} + (\text{PumpLoad} - \text{Threshold}) * \text{Gain}$$

when said load on said pump motor exceeds said Threshold, where PumpLoad is said measured pump motor's load, Threshold is a predefined load threshold value and Gain is a predefined positive feedback gain value.

13. The method of claim 9 or 10, wherein:

said pump motor consisting of a pulsed activation, permanent magnet DC motor;

said load measuring step including measuring said pump motor's current;

said speed measuring step including measuring said pump motor's back-emf.

1 / 4

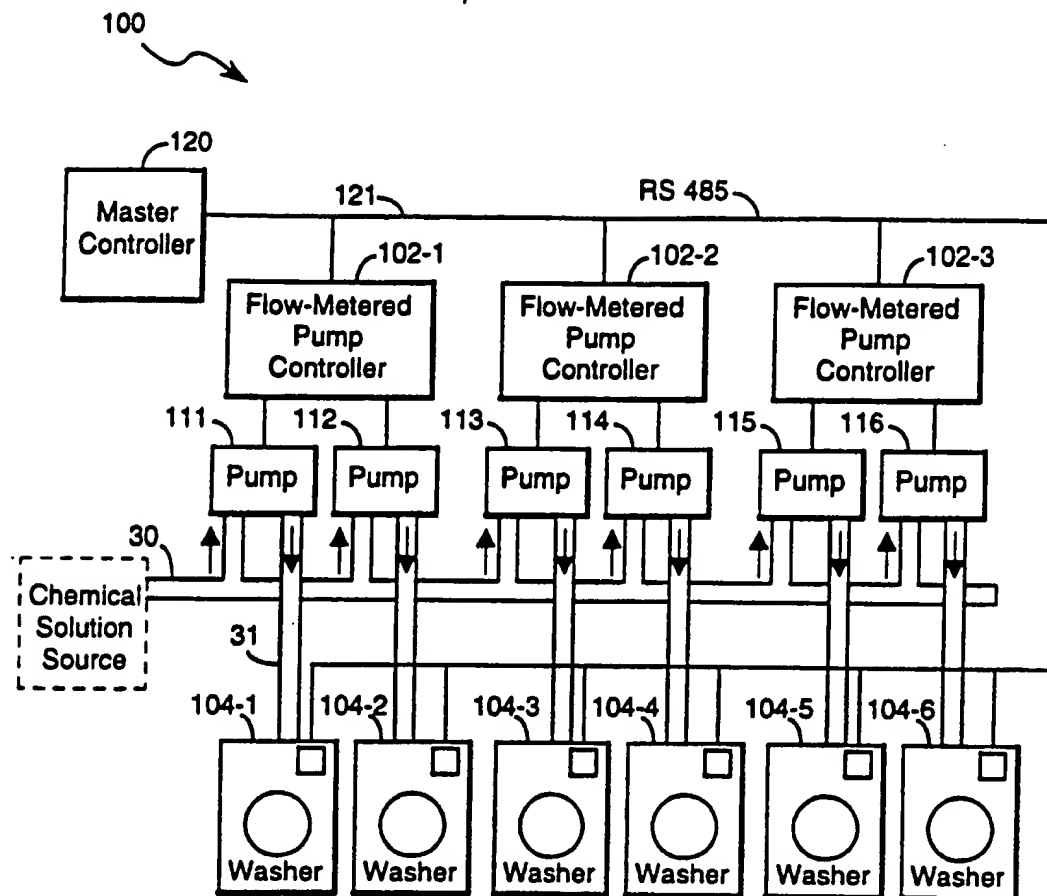


FIGURE 1

SUBSTITUTE SHEET

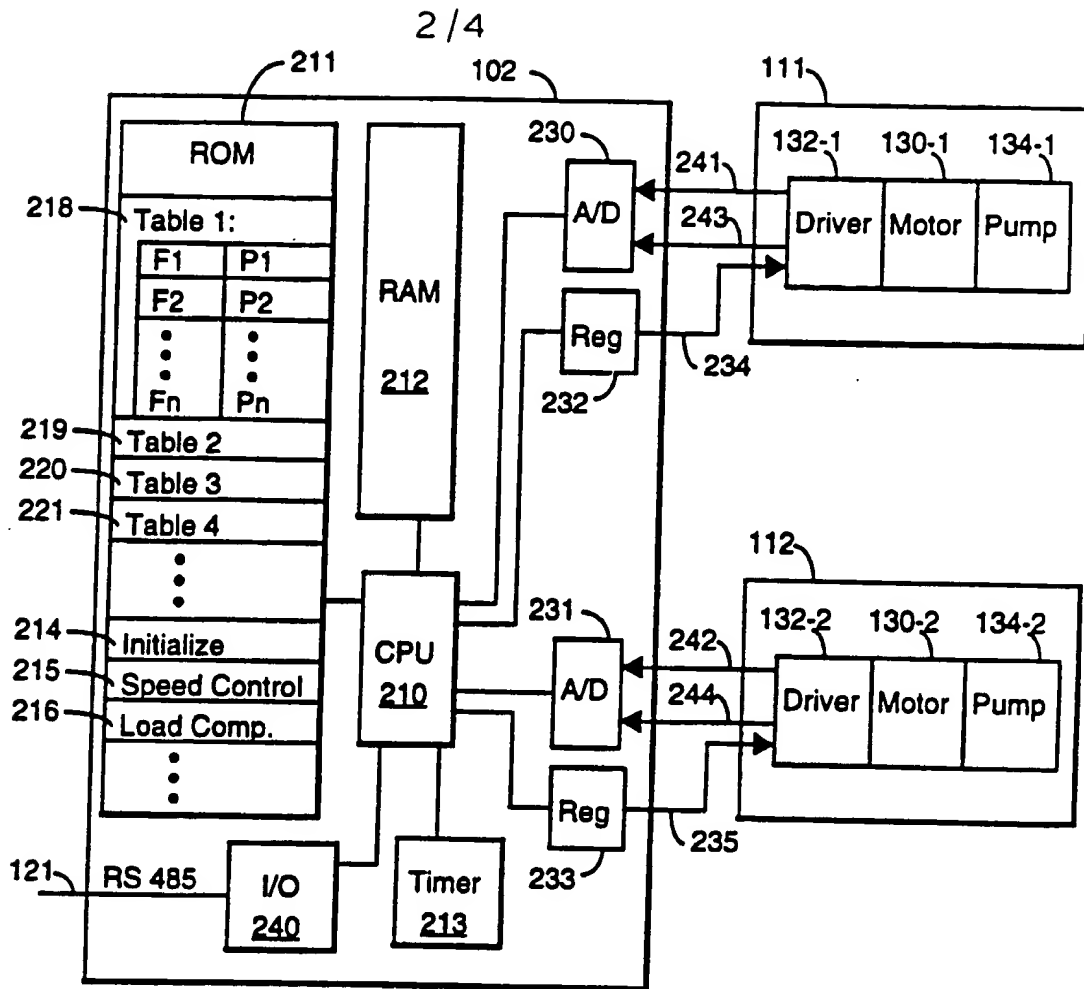


FIGURE 2

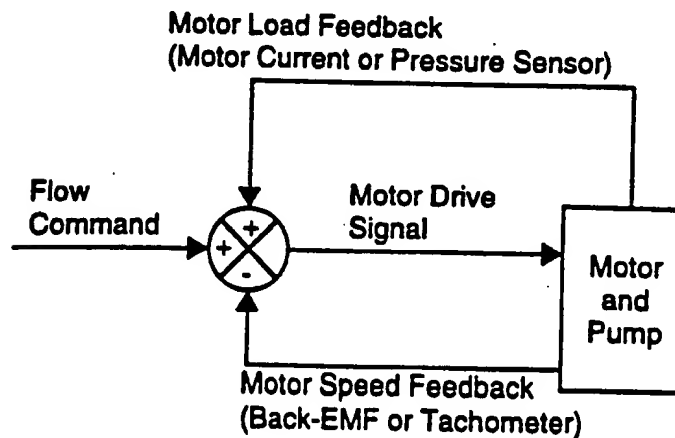


FIGURE 7

3/4

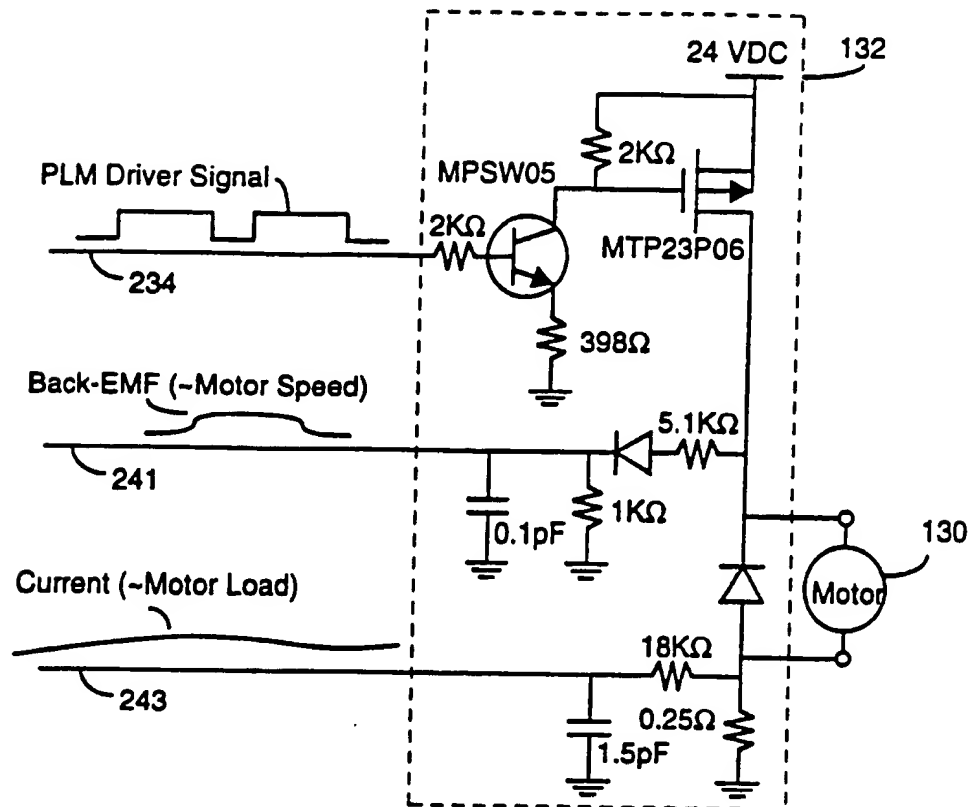


FIGURE 3

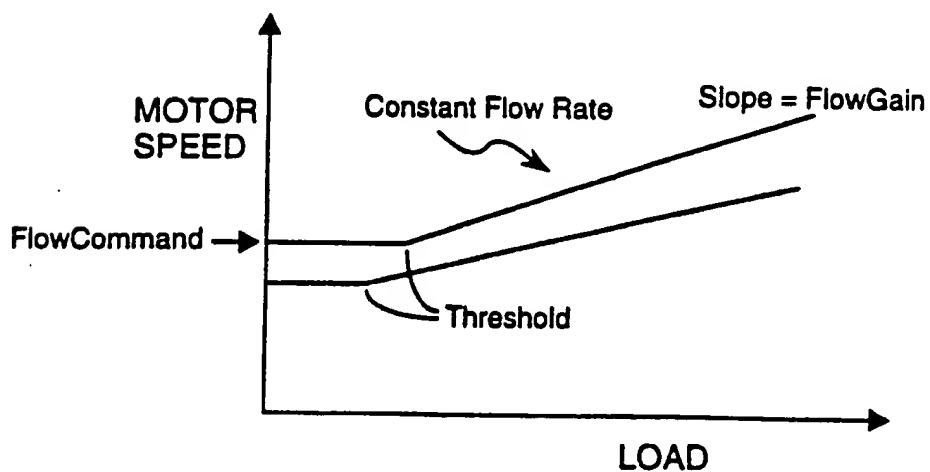


FIGURE 4

SUBSTITUTE SHEET

4 / 4

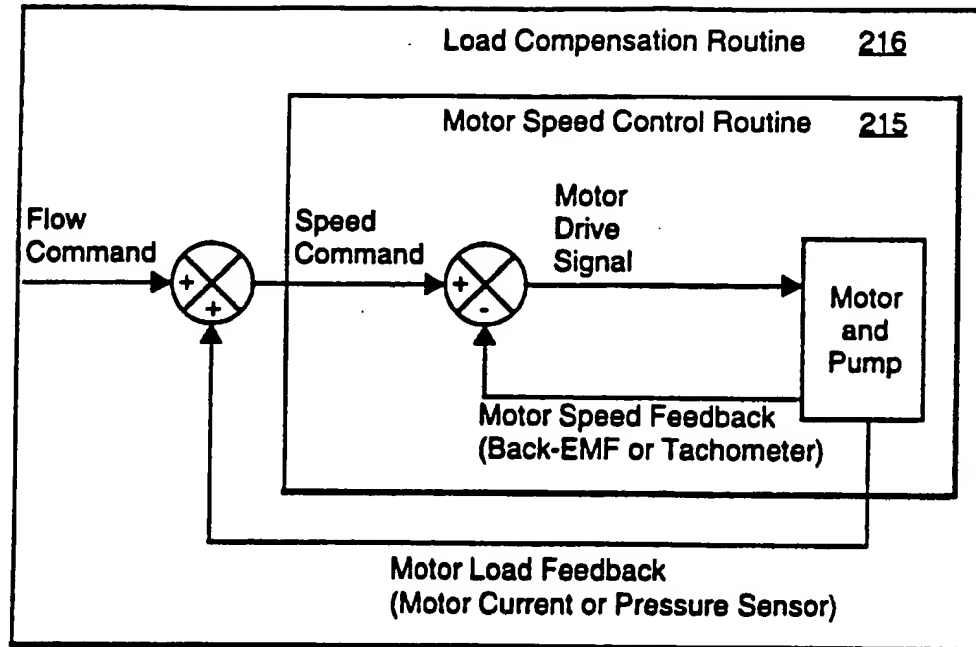


FIGURE 5

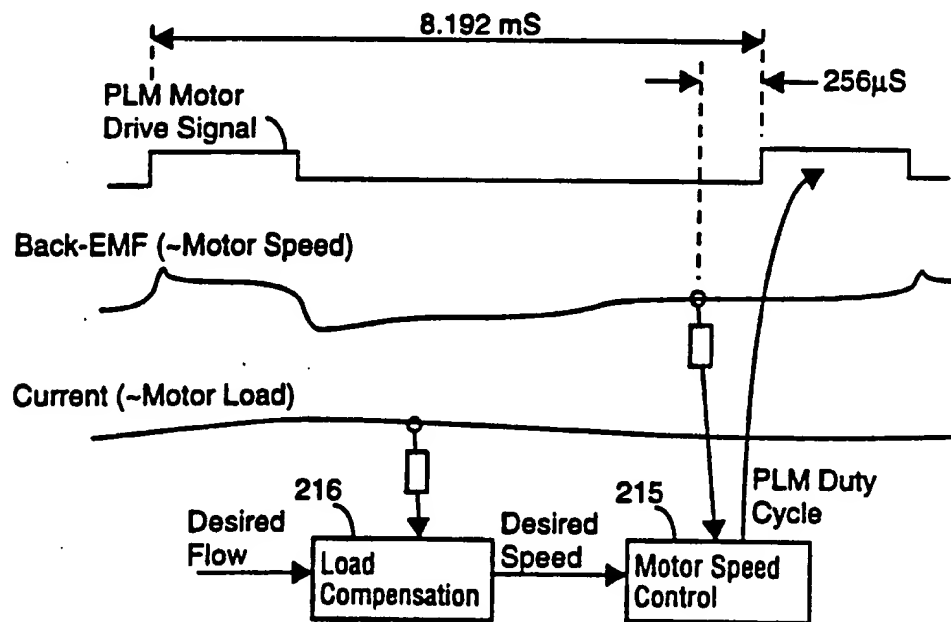


FIGURE 6

SUBSTITUTE SHEET

Internal Application No
DST/CA 94/00517

According to International Patent Classification (IPC) or to both national classification and IPC

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 F04B G05D G05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|--|-----------------------|
| Y | US,A,5 163 818 (BETSILL ET AL) 17 November 1992 | 1,3,7,9, 10 |
| A | see column 5, line 25 - column 10, line 48; figures 4-12 | 2,5,6,8, 12,13 |
| Y | US,A,4 384 825 (THOMAS ET AL) 24 May 1993 | 1,3,7,9, 10 |
| A | see column 2, line 16 - column 4, line 56; figures 1,2 | 4,11 |
| A | US,A,5 141 402 (BLOOMQUIST ET AL) 25 August 1992 see column 3, line 30 - column 7, line 10; figures 1-6 | 1,3,9,10 |
| | -/-- | |

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "I" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

*& document member of the same patent family

Date of the actual completion of the international search

23 December 1994

Date of mailing of the international search report

13.01.95

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+ 31-70) 340-3016

Authorized officer

Calarasanu, P

INTERNATIONAL SEARCH REPORT

Inte nal Application No

PCT/CA 94/00517

| C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT | | |
|--|--|-----------------------|
| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
| A | US,A,4 552 513 (MILLER ET AL) 12 November 1985 see column 6, line 21 - column 8, line 56; figures 6-8 --- | 1-3,5,6, 9,10,12 |
| A | US,A,4 209 258 (OAKES) 24 June 1980 see column 2, line 56 - column 4, line 41; figures 1A,1B ----- | 1,7-9,13 |

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/CA 94/00517

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---------------------|----------------------------|---------------------|
| US-A-5163818 | 17-11-92 | NONE | |
| US-A-4384825 | 24-05-83 | CA-A- 1150802 | 26-07-83 |
| US-A-5141402 | 25-08-92 | EP-A- 0574623 | 22-12-93 |
| US-A-4552513 | 12-11-85 | NONE | |
| US-A-4209258 | 24-06-80 | NONE | |

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☐ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.